# CHARACTERIZATION OF SOFT SOIL USING MULTI-CHANNEL ANALYSIS OF SURFACE WAVES (MASW) AND ELECTRICAL RESISTIVITY METHOD (ERM)

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For my beloved mother and father

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## ABSTRACT

This thesis demonstrates the research on the soft soil characteristics using geophysical methods. The need on non-intrusive, time efficient, economic and larger volume of investigation had increased the demand of using geophysical methods for geotechnical investigation. The research concentrates on the determination of soft soil shear-wave velocity (Vs) profile using the multi-channel analysis of surface waves (MASW) and the soil stratigraphy using Electrical Resistivity Method (ERM). The soft soil Vs and stratigraphy were determined and correlated with the peat sampler and borehole data to obtain more accurate data. The research was conducted at Parit Nipah and RECESS UTHM. The Vs obtained for peat and soft clay at Parit Nipah was in the range of 29.7 to 34.9 m/s and 36.8 to 76.9 m/s respectively. While, the soft clay Vs obtained at RECESS was in the range of 64.4 to 124.0 m/s. The lower Vs obtained on peat compared to soft clay was due to the heterogeneity of peat. The soil strata obtained by ERM had good agreement with the peat sampler and borehole data. The resistivity value of peat and soft clay obtained at Parit Nipah was in the range of 47.2 to 127.7 ohm.m and 9.4 to 25.8 ohm.m correspondingly. While, at RECESS soft clay, the resistivity value was in the range of 1.0 to 4.6 ohm.m. The lower resistivity value of soft clay was governed by the amount of clay fraction which was related to cation exchange capacity (CEC). As higher CEC results in higher conductivity. The relationship obtained between the 1-D Vs and 1-D resistivity value shows that consistent value of peat Vs was followed by the slight decrease in peat resistivity value. While, drastic increase in soft clay Vs results in a significant decrease in soft clay resistivity value. This concluded that stiffness does not produce significant effect on the soil resistivity. Overall, MASW and ERM produced high quality data for subsurface investigation in larger volume with timely efficient manner and more economic.

# ABSTRAK

Tesis ini menunjukkan kajian mengenai ciri-ciri tanah lembut menggunakan kaedah geofizik. Keperluan terhadap kajian tidak intrusif, cekap masa, ekonomi dan isipadu kajian yang lebih besar telah meningkatkan permintaan terhadap kaedah geofizik untuk kajian geoteknik. Kajian ini difokuskan dalam mendapatkan ciri-ciri berkenaan halaju gelombang ricih tanah lembut menggunakan kaedah *Multichannel Analysis of Surface Waves (MASW)* dan mengenal pasti jenis strata tanah menggunakan *Electrical Resistivity Method (ERM)*. Halaju gelombang ricih tanah lembut dan strata tanah diwujudkan dan dibandingkan dengan maklumat tanah yang diperoleh dari penyampel tanah gambut dan lubang gerudi untuk memperoleh data yang lebih tepat. Kajian ini telah dijalankan di Parit Nipah, dan RECESS UTHM. Halaju gelombang ricih yang diperolehi untuk tanah gambut dan tanah liat lembut di Parit Nipah adalah masing-masing dalam lingkungan 29.7 ke 34.9 m/s dan 36.8 ke 76.9 m/s. Manakala, bagi tanah liat lembut yang diperoleh di RECESS adalah dalam lingkungan 64.4 ke 124.0 m/s. Halaju gelombang ricih yang rendah diperoleh di tanah gambut berbanding tanah liat lembut adalah kerana sifat kepelbagaian yang terdapat pada tanah gambut. Lapisan strata tanah yang diperoleh menggunakan kaedah *ERM* dipersetujui oleh data pensampel tanah gambut dan data lubang gerudi. Nilai kerintangan tanah gambut dan tanah liat lembut yang diperoleh di Parit Nipah adalah sejajar dalam lingkungan 47.2 ke 127.7 ohm.m dan 9.4 ke 25.8 ohm.m. Manakala, pada tanah liat lembut RECESS, nilai kerintangan adalah dalam lingkungan 1.0 ke 4.6 ohm.m. Nilai kerintangan pada tanah liat lembut yang rendah dipengaruhi oleh bilangan pecahan tanah liat yang berkait rapat dengan kapasiti pertukaran kation. Kadar kapasiti pertukaran kation yang tinggi menyumbang kepada kekonduksian yang tinggi. Hubungkait di antara halaju gelombang ricih tanah satu dimensi dan nilai kerintangan satu dimensi menunjukkan bahawa nilai konsisten halaju gelombang ricih tanah gambut diikuti dengan sedikit penurunan pada nilai kerintangan tanah gambut. Manakala, penurunan drastik pada halaju gelombang ricih tanah menghasilkan sedikit penurunan pada nilai kerintangan tanah liat lembut. Dapat disimpulkan bahawa kekakuan tidak menghasilkan kesan ketara terhadap kerintangan tanah. Secara keseluruhan, *MASW* dan *ERM* menghasilkan data berkualiti untuk kajian sub strata tanah untuk isipadu yang lebih besar dengan kaedah lebih berkesan dan lebih ekonomi.

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## LIST OF SYMBOLS AND ABBREVIATIONS

| | |
|---|---|
| c | Damping coefficient |
| $c_c$ | Critical damping coefficient |
| CEC | Cation exchange capacity |
| D | Damping ratio |
| $D_{min}$ | Minimum damping ratio |
| dx | Receiver spacing |
| ERM | Electrical Resistivity Method |
| f-v | Frequency-velocity |
| $G_{max}$ | Maximum shear modulus |
| h | Thickness |
| I | Current |
| Lo | Array line offset distance |
| MASW | Multichannel Analysis of Surface waves |
| $\rho$ | Density |
| R | Resistance |
| RMS | Root mean square |
| RMSE | Root mean square error |
| S/N | Signal to noise |
| V | Voltage |
| $V_p$ | P-wave velocity |
| $V_s$ | Shear-wave velocity |
| $X_1$ | Source offset |
| $Z_{max}$ | Maximum depth of investigation |

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# CHAPTER 1

# INTRODUCTION

## 1.1 Research background

Nowadays, geophysical method had been widely used in geotechnical investigation. Some of the methods which are commonly used are Multichannel Analysis of Surface Waves (MASW) and Electrical Resistivity Method (ERM). The application of the geophysical method in soil investigation, especially concerning soft soil is very limited. Hence, this research focused on the application of geophysical method on the soft soil investigation.

Geophysics method, such as MASW is designed to map spatial variations in the physical properties of soil. The main advantage of MASW is its ability to take into full account the complicated nature of seismic waves that always contain noise such as unwanted higher modes of surface waves, body waves, scattered waves, traffic waves, etc., as well as fundamental-mode surface waves (Park et al., 2007). The MASW method is divided into two, which are, active and passive. The active MASW method was introduced in geophysics in 1999. It adopts the conventional mode of survey using an active seismic source (e.g., a sledge hammer). It utilizes surface waves propagating horizontally along the surface of the measurement directly from the impact point to receivers. MASW also gives shear-wave velocity (Vs) information in either 1-D (depth) or 2-D (depth and surface location) format at a cost effective and time-efficient manner. The maximum depth of investigation ($z_{max}$) is usually less than 30 m, but this can vary with the site and type of active source used (Park et al., 2007).

The ERM is a geophysical method used to determine the subsurface resistivity distribution by injecting current into the ground through two current electrodes (C1 and C2), and measuring the resulting voltage difference at two potential electrodes (P1 and P2) (Loke, 1999). The Electrical Resistivity Method comprises of a 1-D sounding survey, 2-D imaging survey and 3-D surveys. The ability of 2-D Earth resistivity measurement to map the electrical resistivity distribution in the Earth allows the estimation of the subsurface heterogeneity (Slob, 2004).

Soft soil is considered as challenging soil especially due to its special features and high degree of compressibility. Peat is a representative material of soft soils and classified as highly organic with organic content more than 75% (Kolay et al., 2011). It is brownish in color and is formed by decomposed organic matter that have accumulated over a thousand years, with lack of oxygen and under waterlogged conditions. Peat is well known to deform and fail under light surcharge load, and it is characterized with low shear strength (5-20 kPa), high compressibility, high organic content (>75%) and high water content (>200%) (Zainorabidin and Wijeyesekera, 2007). While, clay is a fine-grained soil material that become plastic due to their water content and non-plastic when dried. The clay soil material also combines one or more clay minerals with traces of metal oxides and organic matter.

## 1.2 Problem statement

Geotechnical investigation is a critical pre-construction work especially concerning the soft soil. Various parameters are determined and observed during the investigation which include surface exploration and subsurface exploration. Dynamic soil properties and soil stratigraphy are some important parameters in subsurface exploration. Dynamic soil properties determination especially the shear-wave velocity is considered an important parameter when dealing with super structure and large construction. As mentioned by Ivanov et al. (2015), stiffness properties of near surface materials are important for engineering applications and shear-wave velocity is directly related to stiffness. It is also a critical parameters in geotechnical earthquake engineering problems. While, the soil stratigraphy provides description of the soil physical characteristics.

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